MEASUREMENT AND ANALYSIS OF PATIENT ATTENUATION CORRECTION FACTOR DURING RADIOIODINE THERAPY

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The calculated dose rate from the radioiodine therapy patient should normally include a factor accounting for the attenuation and scatter of patient body tissues. The attenuation factor is currently neglected, and not applied in operational radiation protection. Realistic estimation of radiation dose levels from radioiodine therapy patients when properly performed will reduce operational cost and optimise institutional radiation protection practice. In this work, the existence of a patient body tissue attenuation factor is verified by comparing the dose rates measured from the radioiodine capsules immediately before administration with those measured from the patient immediately after administration. The correlation between the factors suspected to influence the patient body tissue attenuation and the measured dose rates from the patient normalised per unit activity is statistically analysed. The calculated attenuation correction factor based on authors’ measurements was (0.55 ± 0.17). The measured dose rate per unit of radioactivity from the patient showed a negative correlation with their body mass index.

INTRODUCTION

For more than 50 years, radioiodine has been used in the treatment of different benign and malignant thyroid diseases. Radioiodine therapy (RIT) is the most practised type of radionuclide therapy in our institution. We treat annually around 100 patients; these patients are admitted in two treatment rooms specially designed for inpatient treatment of radioiodine.

The difference between theoretical expected dose rate value from the patient and the measured one is mainly attributed to the patient body tissue attenuation. The correlation between the measured exposure rate from the patients and their body mass index (BMI) and body weight was studied and the results are presented. Calculated statistical parameters, namely Pearson coefficient of correlation ($r$), coefficient of determination ($r^2$) and the level of significance known as the ($p$) value were used to assess the degree of significance of the relationship between the measured exposure rates and some of the patient physical characteristics suspected to influence the attenuation factor.

It has been reported by Siegel et al. (1) that it is more realistic to use the line source approximation than the point source when reporting theoretical dose rates to exposed hospital staff from the radioactive patient as an alternative to actual dose rate measurements. The measured dose rate at 1 m per unit of administered activity predictably decreased with increasing patient size expressed as BMI because of increasing photon attenuation (2).

Correction factors to be applied to the dose rate measurements to account for attenuation and scatter in the exposed individual have been proposed. In the case of Iodine-131, the measured dose rate at 1 m, which reflects only the surface entrance dose rate to the exposed individual, should be multiplied by 0.62 to correctly reflect the total-body dose rate as proposed by Sparks et al. (3).

Yi et al. (4) proposed a self-shielding factor for the point source model to be 0.6 ± 0.16. In another study, Willegaignon et al. (5) modelled the correction factor to be equal to 0.638 when dose rates are measured at 1 m from the patient.

The calculated dose rate from the patient should normally be estimated as the gamma exposure rate constant multiplied by a factor accounting for patient body tissue attenuation. The aim of this work was to measure the patient attenuation correction factor (ACF) using direct dose rate measurements routinely performed during patient hospitalisation in the institution.

MATERIALS AND METHODS

The dose rates were measured from the patients immediately after administration of the radioiodine capsules at 1 m anterior to the patient body surface facing the abdominal region. The measured dose rates were compared with the dose rate measured from the unshielded radioiodine capsules measured immediately before administration in order to avoid correcting for radioactive decay.

The dose rate meter type used to measure the dose rates in this study was Ionisation chamber (Thermo, Smart Ion, Type: 2120G). The activity of the capsules was measured using clinical dose calibrator (Capintec, CRC-15R).

The dose rate at 1 m from the unshielded $^{131}$I capsules measured in $\mu$Sv h$^{-1}$ was divided by the activity measured in GBq to obtain the normalised dose rate per unit activity. All patients in the study were
surveyed using the same calibrated dose rate meter; the meter has a valid calibration certificate from a nationally accredited secondary standard laboratory (SSDL) and classified by the IAEA.

In order to minimise the subjective error while performing dose rate measurements at 1 m from the capsules or the patients, the measurements were done by the same staff member from the medical physics department.

The dose rate from a patient containing radioactive material can be estimated using a point source model and given by

$$D = \Gamma A_0/r^2$$

where \(r\) is the distance from the source to the measurement point usually located at 1 m; \(\Gamma\) is the gamma exposure rate constant reported to be 59.5 \(\mu\)Gy h\(^{-1}\) m\(^{-2}\) MBq\(^{-1}\) and \(A_0\) is the administered activity in MBq\(^{6}\).

The ratio of the measured dose rate to the calculated dose rate from the unshielded capsules was (1.04) for the instrument used in the survey; the instrument response was within 4 % from the expected value.

The following can be assumed: the ratio of the dose rate measured from the patient (\(D_P\)) to the one measured from the unshielded capsules (\(D_{\text{cap}}\)) equals the patient attenuation correction factor (ACF).

$$D_P = D_{\text{cap}} \times ACF$$

The existence of a relationship between the (ACF) and the patient's body thickness is hypothesised; the radioiodine photons will be attenuated by absorption and scatter while passing through the body tissues.

The patient body mass index (BMI) in kg m\(^{-2}\) is defined by

$$\text{BMI} = W/H^2$$

where \(W\) is the weight in kilograms (kg) and \(H\) is the height in meters (m).

RESULTS

Patient attenuation correction factor

The average in air dose rate per unit activity from the capsules was found to be 69 \(\mu\)Sv h\(^{-1}\) GBq\(^{-1}\), with a standard deviation of 7 and a coefficient of variation of 10.8.

The ACF was calculated as the ratio of dose rate with attenuation (from the patient) to the dose rate without attenuation (dose rate in air). The average ACF was found to be 0.55 ± 0.17. Figure 1 shows the relationship between the measured dose rate from the patients and the measured dose rate from the unshielded capsules.

The uncertainty level is due to the positioning distance and the dose rate values errors. The uncertainty levels are in the same order of magnitude as other published studies\(^7\).

The measured average whole-body dose rate at 1 m from the surveyed patients and normalised per unit of administered activity was 38.4 ± 11.8 \(\mu\)Sv h\(^{-1}\) GBq\(^{-1}\).

Statistical analysis

The correlation between the different variables in the data was assessed using linear regression by calculating the Pearson correlation coefficient (\(r\)) and the coefficient of determination (\(r^2\)) and the significance level (\(p\)) value, which are all presented in Table 1.

The measured dose rate per unit activity from the patient showed a negative and non-significant correlation with their BMI (Figure 2). There was also a non-significant correlation between the patient weight in kilograms and the dose rate per unit activity.

DISCUSSION

The measured average whole-body dose rate at 1 m from the surveyed patients and normalised per unit of administered activity was 38.4 \(\mu\)Sv h\(^{-1}\) GBq\(^{-1}\). These results are in agreement with the results reported by Barquero et al.\(^8\) who reported an average normalised dose of 52.8 ± 11.4 \(\mu\)Sv h\(^{-1}\) GBq\(^{-1}\). O’Doherty et al.\(^7\) reported an average normalised dose of 60 \(\mu\)Sv h\(^{-1}\) GBq\(^{-1}\) with a range of 50–80 \(\mu\)Sv h\(^{-1}\) GBq\(^{-1}\) and also reported a patient population size of 60 with the average age, weight and height was 59.6 y, 62.2 kg and 162.7 cm, respectively. Table 2 shows patients demographics.
Measurements of patients’ dose rate at a fixed distance have been used as a discharge criterion in some countries. External exposure rate method has been frequently used for monitoring of $^{131}$I patients’ body burden(9).

A strict application of regulation of radioactive materials used in medical facilities in some countries has created a large waiting list for patients diagnosed with differentiated thyroid cancer (DTC) and referred for radioiodine therapy (RIT) post-thyroidectomy. Hospital admission is mandatory in Japan for RIT in patients with DTC, because the use of more than 500 MBq of $^{131}$I on an outpatient basis is prohibited. It has been reported by Higashi et al. (10) that a delay in the treatment delivery for non-medical reasons has resulted in a negative survival outcome for the group of patients with DTC in Japan. It is clear from this example that application of restrictive regulations when it is not necessary could be harmful. There is a need to investigate and probably apply more realistic radiation protection regulations based on practical evidence and on the results of multiple risk assessment exercises published in the scientific literature over the past years(11–15); these studies have demonstrated the safe nature of radioiodine therapy as an outpatient treatment modality.

Lee and Park(16) reported that if the total admission time in the hospital can be shortened while maintaining safety regulations, more patients who need high dose radioiodine therapy can be treated. Some patients complain about the inconvenience of isolation and the anxiety that they experience from solitude. The dose calculations based on the measured dose rate at 1 m and patient-specific factors will significantly overestimate the actual dose to others from patients released after $^{131}$I therapy(3). The primary reason for this is that the patient dose rate is a measurement of surface entrance dose rate with no correction for attenuation by the body of the exposed individual(2). It can be seen from the previous statement that body attenuation can be applied to both the source of radiation (i.e. the patient) and the target (i.e. the exposed individuals).

The current patient release criterion based on the total effective dose equivalent evaluated at 1 m from the patient is safe, since there is an overestimation of the estimated dose rate from the patient because scatter and attenuation by body tissues are not taken into consideration. The instructions given to the patient post-release regarding radiation safety precautions are sufficiently conservative. The application of a more accurate estimation of the predicted radiation dose rate from the patient will allow the patient to be released earlier from hospital confinement, therefore reducing hospitalisation cost and benefiting the patients and their families personally and psychologically.

Radiation shielding materials are often incorporated in the walls of the treatment rooms to protect adjacent

### Table 1. Results of Pearson correlation coefficient ($r$), coefficient of determination ($r^2$) the level of significance at 0.01 two-tailed probability ($p$) value; the number of patients in this study is 80.

<table>
<thead>
<tr>
<th>Variable 1</th>
<th>Variable 2</th>
<th>$r$ value</th>
<th>$r^2$ value</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose from capsules (unshielded)</td>
<td>Dose from patients (shielded)</td>
<td>0.560</td>
<td>0.314</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BMI (kg m$^{-2}$)</td>
<td>Measured normalised dose rate ($\mu$Sv h$^{-1}$ GBq$^{-1}$)</td>
<td>-0.1771</td>
<td>0.0313</td>
<td>0.116</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>Measured normalised dose rate ($\mu$Sv h$^{-1}$ GBq$^{-1}$)</td>
<td>-0.2146</td>
<td>0.0461</td>
<td>0.056</td>
</tr>
</tbody>
</table>

### Table 2. Patient demographics.

<table>
<thead>
<tr>
<th>Data element</th>
<th>Average value</th>
<th>Data range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients included in the study</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>48</td>
<td>13–91</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>78</td>
<td>43–135</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>158</td>
<td>130–195</td>
</tr>
<tr>
<td>BMI (kg m$^{-2}$)</td>
<td>31.3</td>
<td>17.4–50.9</td>
</tr>
<tr>
<td>Administered activity (MBq)</td>
<td>4357</td>
<td>1805–7910</td>
</tr>
<tr>
<td>Measured normalised dose rate ($\mu$Sv h$^{-1}$ GBq$^{-1}$)</td>
<td>38.4</td>
<td>19.9–67.0</td>
</tr>
<tr>
<td>Attenuation factor</td>
<td>0.55</td>
<td>0.28–0.96</td>
</tr>
</tbody>
</table>

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Radiation shielding materials are often incorporated in the walls of the treatment rooms to protect adjacent
areas. Patient body attenuation is not considered in the
shielding design calculations. More practical and eco-
nomical assumptions can be proposed when patient’s
ACF is taken into account in the shielding design cal-
culations. Significant cost reduction can be achieved.

The normalised dose rate per unit activity measured
from the patient can be used to formulate more reason-
able written safety instructions given to the patients
upon release from the hospital. Such a dose rate is di-
rectly measured from the patients which includes body
attenuation.

In this work, a simple method for measuring the
patient attenuation factor based on dose rate mea-
surements in μSv h⁻¹ as a function of the ¹³¹I capsule
activity in MBq and the routinely measured dose rates
from the patient post-administration has been pre-
sented. The measured attenuation factor can be cur-
tently used to predict the dose rates from the patients in
situation where direct dose rate measurements are not
possible, like in accidental dose reconstruction scen-
arios, where dose estimations are required. It can be
also used in radiation risk assessment performed by radia-
tion protection personnel.

CONCLUSION

A more accurate theoretical estimation of radiation
dose to individuals exposed to radioactive patients
based on the administered activity and taking into
account the ACF is possible when direct dose rate
measurements are not possible.

Radiation safety specialist performing risk assess-
ments, shielding design and developing safety instruc-
tions to the released patient after radiiodine therapy
could benefit from the measured ACF.

REFERENCES

1. Siegel, J. A., Marcus, C. S. and Sparks, R. B.
   Calculating the absorbed dose from radioactive patients:
   43(9), 1241–1244 (2002).

2. Siegel, J. A., Kroll, S., Regan, D., Kaminski, M. S. and
   Wahl, R. L. A practical methodology for patient release
   after tositumomab and ¹³¹I-tositumomab therapy. J. Nucl.

3. Sparks, R. B., Siegel, J. A. and Wahl, R. L. The need for
   better methods to determine release criteria for patients
   administered radioactive material. Health. Phys. 75,

4. Yi, Y., Stabin, M. G., McKaskle, M. H., Shone, M. D.
   and Johnson, A. B. Comparison of measured and calcu-
lated dose rates near nuclear medicine patients. Health

5. Willegaignon, J., Guimaraes, M. I., Stabin, M. G.,
   Sapienza, M. T., Malvestiti, L. F., Marone, M. M. and
   Sordi, G. M. Correction factors for more accurate esti-
mates of exposure rates near radioactive patients: experi-
   93(6), 678–688 (2007).

6. Smith, D. S and Stabin, M. G. Exposure rate constants
   and lead shielding values for over 1,100 radionuclides.

7. O’Doherty, M. J., Kettle, A. G., Eustance, C. N.,
   Mountford, P. J and Coakley, A. J. Radiation dose rates
   from adult patients receiving ¹³¹I therapy for thyrotoxi-

8. Barquero, R., Basurto, F., Vega-Carrillo, H. R., Iniguez,
   M. P., Ferrer, N. and Esteban, R. Correlation between
   external exposure and activity in patients undergoing ¹³¹I
   thyroid cancer therapy. Health Phys. 95(2), 227–233
   (2008).

9. Tabej, F., Neshandar, Asli., Azizmohammadi, Z.,
   Javadi, H. and Assadi, M. Assessment of radioiodine
   clearance in patients with differentiated thyroid cancer.

10. Higashi, T. et al. Delayed initial radioactive iodine therapy
    resulted in poor survival in patients with metastatic differen-
    tiated thyroid carcinoma: a retrospective statistical analysis

    Radiation exposure from outpatient radioactive iodine
    (¹³¹I) therapy for thyroid carcinoma. JAMA 283(17),

12. Rutar, F. J., Augustine, S. C., Colcher, D., Siegel, J. A.,
    Jacobson, D. A., Tempero, M. A., Dukat, V. J.,
    Hohenstein, M. A., Gobar, L. S. and Vose, J. M.
    Outpatient treatment with (¹³¹I)-anti-B1 antibody: radi-
    ation exposure to family members. J. Nucl. Med. 42(6),

13. Venencia, C. D., Germanier, A. G., Bustos, S. R.,
    Giovannini, A. A. and Wyse, E. P. Hospital discharge of
    patients with thyroid carcinoma treated with ¹³¹I. J. Nucl.

    Thomson, W. H., Batchelor, S., Mountford, P. J.,
    Harding, L. K. and O’Doherty, M. J. Measurement of
    the internal dose to families of outpatients treated with
    Imaging 35(11), 2097–2104 (2008).

15. de Carvalho, A. B. Jr., Hunt, J., Silva, A. X. and
    Garcia, F. Use of a voxel phantom as a source and a
    second voxel phantom as a target to calculate effective
doses in individuals exposed to patients treated with ¹³¹I.

16. Lee, J. H and Park, S. G. Estimation of the release time
    from isolation for patients with differentiated thyroid

17. Marcus, C. S. and Siegel, J. A. NRC absorbed dose re-
    construction for family member of ¹³¹I therapy patient:
    case study and commentary. J. Nucl. Med. 45, 13N–16N
    (2004).